

# Performance Status of the Mars Environmental Compatibility Assessment Electrometer

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## Abstract

The Mars Environmental Compatibility Assessment electrometer is an instrument intended to fly on a future Mars lander mission. The electrometer was designed primarily to investigate (1) the electrostatic interaction between the Martian soil and five different types of insulators attached to the electrometer, which are to be rubbed over the Martian soil. The MECA Electrometer is also capable of measuring (2) the presence of charged particles in the Martian atmosphere, (3) the local electric field strength, and (4) the local temperature. We have tested and evaluated the measurement capabilities of the MECA Electrometer under simulated Martian surface conditions using facilities located in the Electromagnetic Physics Testbed at KSC. The results of the study have demonstrated that rubbing an insulator over the Martian soil simulant does triboelectrically charge up the insulator's surface. However, the charge buildup on an insulator was found to be as low as 1% of the current maximum range of the electrometer when it is rubbed through Martian soil. This indicates that the overall gain of the MECA Electrometer could be increased by a factor of 50, if measurements at the 50% level of full-range sensitivity are desired. The ion gauge, which detects the presence of charged particles, was also evaluated over the pressure range 13 - 533 mbar, and results will be presented.

## 1. Introduction

The Mars Environmental Compatibility Assessment (MECA) Electrometer was designed jointly at NASA's Jet Propulsion Laboratory and Kennedy Space Center to be a flight instrument for a future unmanned Mars lander mission [1]. The MECA Electrometer was designed primarily to investigate the electrostatic interaction between the surfaces of insulating materials and the soil on the surface of Mars. The insulating materials were selected for their use on previous space missions. The five insulators selected for the MECA Electrometer were: Fiberglass/Epoxy, Polycarbonate (known as Lexan<sup>TM</sup>), Polytetrafluoroethylene (Teflon<sup>TM</sup>), Rulon J<sup>TM</sup>, and Polymethylmethacrylate (Lucite<sup>TM</sup> or PMMA).

It was not the purpose of the research described in this paper to study the electrostatic properties of the five types of insulating materials mounted on the electrometer. Rather, the goal of the research was to test and evaluate the performance of the MECA Electrometer and the four types of measurement sensors it has onboard: (1) triboelectric sensor array, (2) ion gauge (charged particle sensor), (3) local electric field sensor, and (4) temperature sensor.

Testing the triboelectric sensor array (tribo) involved measuring the degree to which the insulator surfaces became electrically charged when rubbed over Martian soil simulant (JSC Mars-1) either at low CO<sub>2</sub> pressure inside a vacuum chamber, or under low humidity conditions at atmospheric pressure using dry air in a glovebox. Ottawa quartz sand and, at the end of the study, Lunar soil simulant were also studied as abrasive mediums that could triboelectrically charge the surfaces of the insulating materials. The ion gauge (IG) was tested using a reliable generator of atmospheric ions. The IG output voltage was measured as a function of CO<sub>2</sub> pressure inside a small vacuum chamber. We tested the electric field sensor (ELF) by applying a fixed voltage to a flat metal plate that was placed above the ELF electrode.

These measurements were conducted at various CO<sub>2</sub> pressures inside a vacuum chamber. Finally, the temperature sensor located inside the MECA Electrometer could not be studied because the Mars vacuum chamber that provides temperature control down to typical Martian surface temperature was still under construction in the Labs and Testbeds Division at KSC. However, the temperature sensor was observed to work properly at room temperature, where all of the measurements were conducted. The data and results of the testing of the MECA Electrometer are presented in the following sections. We conclude with a summary of our evaluations of the MECA Electrometer, and our recommendations for how the MECA Electrometer's performance might be enhanced.

## 2. Results and Discussion

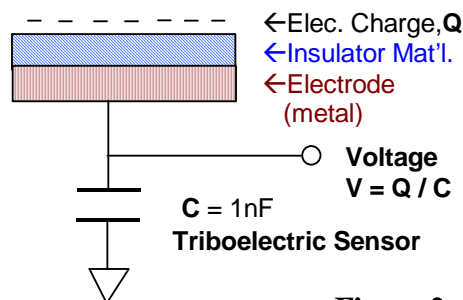
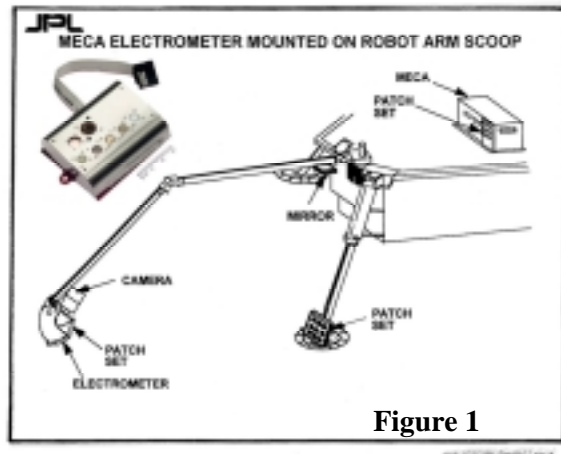
In this section, we describe the four types of measurement sensors contained within the MECA Electrometer. Data taken with the sensors is presented, and each sensor's performance is discussed.

### 2.1 Evaluation of the Triboelectric Sensors

The triboelectric sensor array consists of five insulating materials placed above metal electrodes that are connected to five independent electrometer circuits, one circuit for each type of insulator. The tribo sensors are housed inside the MECA Electrometer, whose case is made of titanium of volume ~50 cm<sup>3</sup>, total mass of ~50 g, and power consumption of <250 mW. Figure 1 contains a picture of the electrometer, and shows how it would be mounted to the heel of the Mars lander's scoop.

The five small circular patches shown in Figure 1 are the five types of insulators. Below these patches are the electrometer circuitry (not shown) that measure the amount of electric charge that develops on the insulator surfaces after the scoop drags the electrometer through the Martian soil. The two openings shown above the five insulators in the electrometer photo are the local electric field sensor (ELF) on the left, and the ion gauge (IG) on the right. The temperature sensor is a dedicated integrated circuit chip that is mounted inside the case, and is not shown in the photo of the MECA Electrometer.

The electronics contained within the MECA Electrometer housing have been described elsewhere [2], and will only be discussed as needed in this paper. The tribo sensor circuit has an output voltage,  $V_{out}$ , that is proportional to the electric charge that develops on the surface of the insulator. The circuit is shown schematically in Figure 2. The overall gain of the tribo circuit (not shown) is 4x. Thus,  $V_{out} = 4Q/C$ , where the fixed capacitor  $C = 1$  nF. So, the charge  $Q$  on the surface of the insulator must be given by  $Q = V_{out} / (4 \times 10^9 \text{ F}^{-1})$ . Hence, the tribo circuit's gain is 0.25 nC/V as measured at the output. If the A/D converter has a 2mV per bit resolution, then the device can detect an amount of electric charge as small as 0.5 pC, which is numerically equivalent to  $3.1 \times 10^6$  electrons or protons.



### 2.1.1 Electrostatic Rubbing Experiment

The tribo sensors were tested using two methods. The first method described here used a “rubbing” machine that allowed the MECA Electrometer to be dragged through soil with the tribo sensors face down in the soil. The horizontal motion of the electrometer was under computer control that allowed the speed and travel distance to be set separately. A speed of 10 mm/sec was suggested as the speed at which the Mars Lander will drag the electrometer through the Martian soil. The size of the rubbing machine did not allow us to perform this type of experiment in a low pressure CO<sub>2</sub> atmosphere in the small vacuum chamber. However, we were able to conduct this rubbing experiment inside a plastic glovebox, into which dry air flowed so as to reduce the humidity within the box. The relative humidity could be brought below 30% by continuously flowing bottled dry air into the box. An air ionizer was used to neutralize the charges that develop on the tribo materials after each measurement was made. Data was taken using the Parallax Basic Stamp II<sup>TM</sup> controlled by a PC laptop running MS-Windows 95<sup>TM</sup>.

Using this experimental setup, the MECA Electrometer could be rubbed over various types of soils, including quartz sand (SiO<sub>2</sub>), Martian soil simulant (JSC Mars-1) [3], and Lunar soil simulant [4]. Only Martian soil simulant was investigated using the rubbing machine. A typical graph of the tribo sensor output voltages versus time are shown in Figure 3. This data was taken at atmospheric pressure in dry air at a relative humidity of 43% with the MECA Electrometer being rubbed over the Martian soil simulant at 10 mm/s. The time between points is 1.4 seconds.

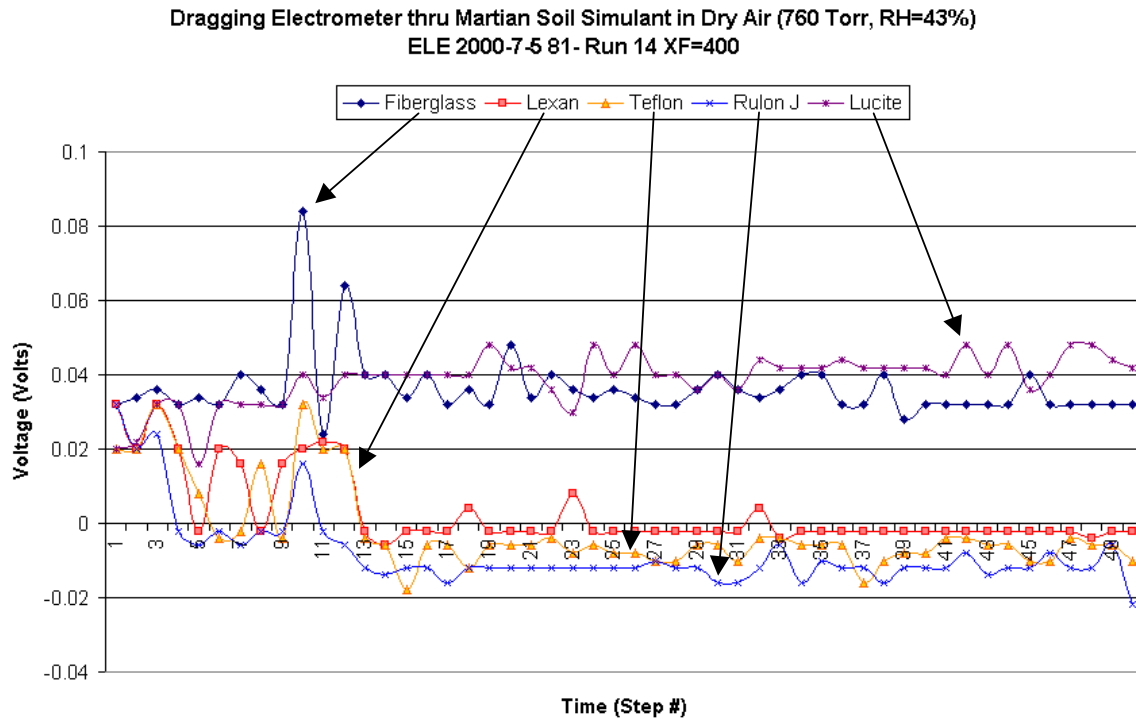
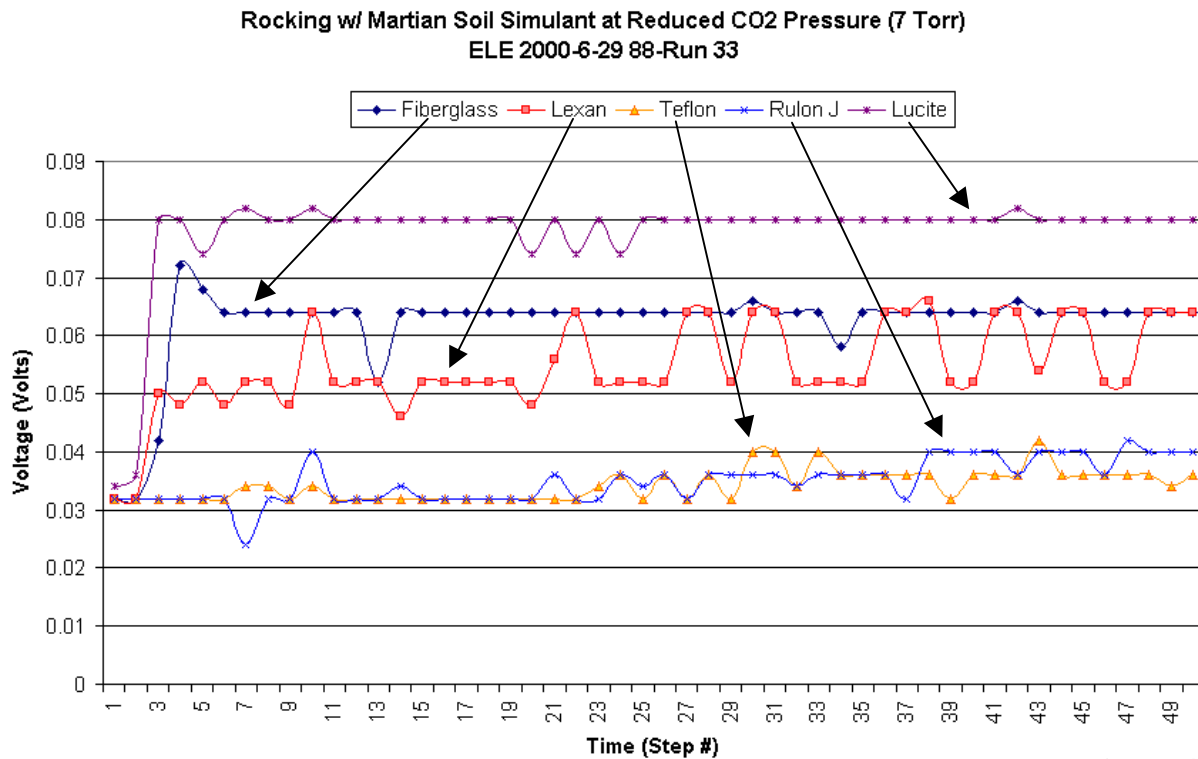


Figure 3 indicates that only small amounts of triboelectric charging will occur when the Martian soil simulant is used. The Rulon J<sup>TM</sup> insulator appears to charge up the most. The tribo voltage for this material changed by -0.04 V, which corresponds to a charge buildup of -10 pC. This is close to the A/D converter resolution of 0.5 pC/bit.

### 2.1.2 Electrostatic Rocking Experiment

Since the rubbing machine could only be operated in dry air at atmospheric pressure, an alternative method of triboelectrically charging the insulators was needed that would work at low CO<sub>2</sub> pressures. A rotary feedthrough mounted on a vacuum chamber was used to rotate an aluminum box containing Martian soil simulant back and forth. The MECA Electrometer was mounted flush with the bottom of the box, and the tribo sensors were facing upwards. As the box was manually rocked back and forth, the soil was able to flow over the tribo sensors and cause the insulators to charge up. Using this experimental setup, it was possible to place 50 g of Martian soil simulant in the box. The vacuum chamber was evacuated of air using a mechanical pump. When a pressure of 1 Torr was reached, CO<sub>2</sub> from a gas cylinder was allowed to flow into the vacuum chamber through a microvalve mounted on the vacuum chamber. This microvalve and a gas regulator attached to the CO<sub>2</sub> cylinder allowed sufficient control of the flow of CO<sub>2</sub> into the chamber that any desired CO<sub>2</sub> pressure could be maintained. Figure 4 shows the tribo sensor responses (data acquired at 1.4 sec time intervals) for the five insulators at 7 Torr CO<sub>2</sub> pressure when Martian soil simulant is used in the rocking experiment. An air ionizer was placed in the vacuum chamber to later neutralize any charge buildup on the tribo material's surfaces.

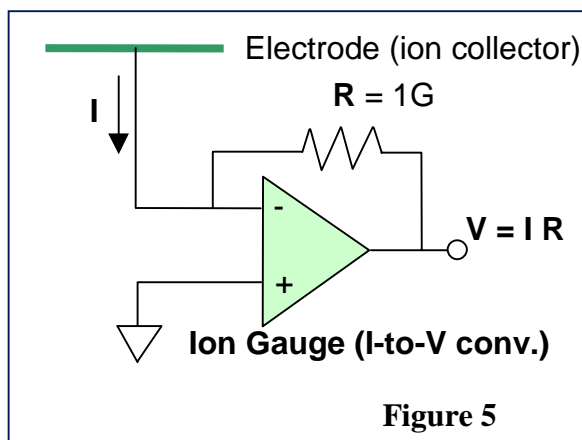


**Figure 4**

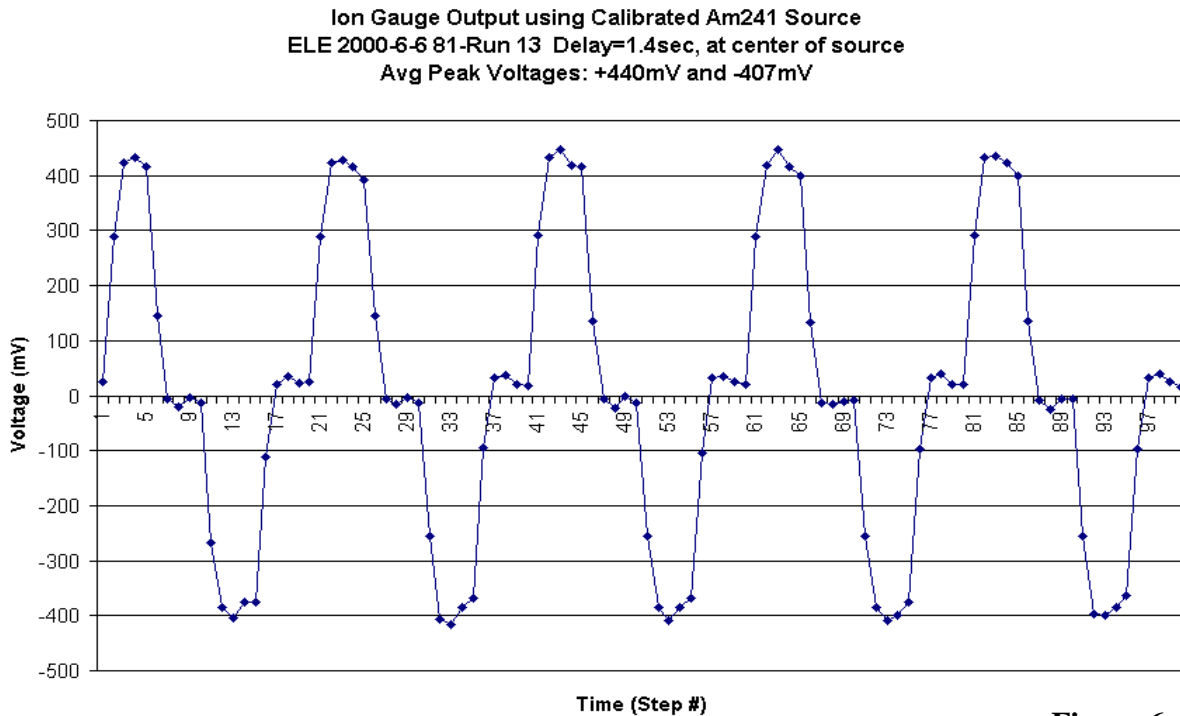
This rocking experiment was repeated at increasing CO<sub>2</sub> pressures with the Martian soil simulant and little change in the tribo sensor responses was discerned. Different and larger responses were obtained when Ottawa quartz sand was used. Whereas the Martian soil simulant tended to charge the tribo sensors positively, the Ottawa sand charged the same materials negatively, or not at all. Lunar soil simulant was also used in the rocking experiment, but only in dry air at atmospheric pressure in the glovebox.

## 2.2 Evaluation of the Ion Gauge

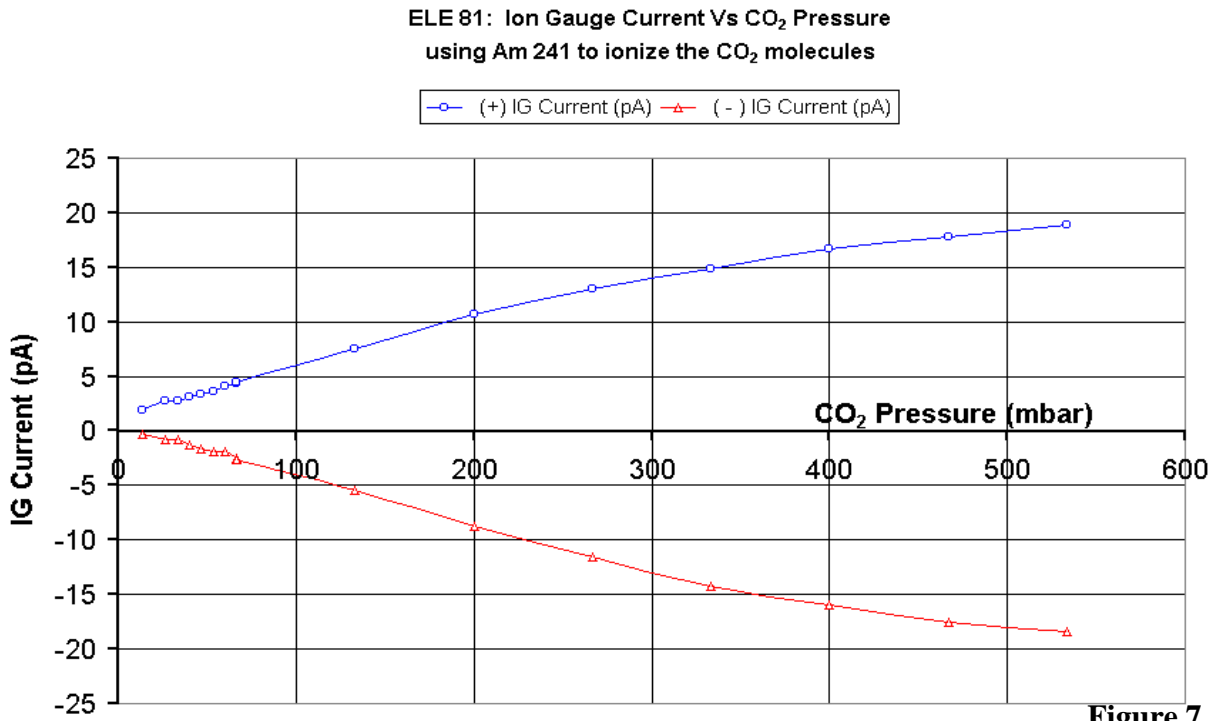
The ion gauge measures the presence of charged particles and atmospheric ions in the vicinity of the MECA Electrometer. The ion gauge circuit is basically a current-to-voltage converter as shown in Figure 5. In the actual circuit, the electrode is held at either a positive or a negative voltage. This causes negative or positive charges, respectively, to accelerate towards the electrode, thus producing the electric current that the circuit detects. The ion gauge was tested using a weak Am 241 source located at a fixed distance above the electrode.



The Am 241 source produces alpha particles that ionize any  $\text{CO}_2$  molecule they collide with. In order to detect the presence of both positive and negative charges, the voltage at the electrode was cycled between the values +3V, 0V, -3V, and 0V. A typical ion gauge sensor response is shown in Figure 6 with the data taken at 5 sec time intervals. From the actual ion gauge circuit, the overall circuit gain was calculated to be 42.2 pA/V. In Figure 6, an output voltage of 420 mV would thus correspond to an ion current of 18 pA. If we assume an A/D converter resolution of 2 mV/bit, the minimum current sensitivity of the ion gauge is found to be 84 fA, which exceeds the input bias current of the operational amplifier. The dependence of the deduced ion gauge current on  $\text{CO}_2$  pressure is shown in Figure 7. Ion current values due to both positive and negative currents are shown.



**Figure 6**



**Figure 7**

### 2.3 Evaluation of the Local Electric Field Sensor

The electric field sensor (ELF) circuit is the same as the tribo sensor circuit, except that the insulator is absent from the top of the electrode. To test the ELF, a metal plate at a fixed voltage is placed at a known distance above the electrode. For the MECA Electrometer, the distance between the plates is approximately 0.3 cm. The ELF sensitivity is calculated using the expression  $(V_{\text{plate}}/d) / V_{\text{ELF}}$  where  $V_{\text{ELF}}$  is the potential difference between the plate and the electrode. The ELF circuit had a voltage offset of +0.032 V. When +1000 V was applied to the plate, the ELF output voltage was measured to be +0.265 V. And when  $V_{\text{plate}} = -1000$  V was used,  $V_{\text{out}} = -0.199$  V. After the offset voltage is taken into account, we find  $|V_{\text{ELF}}| = 0.231$  V. The sensitivity of the ELF is then calculated to be  $(1000\text{V}) / (0.3\text{cm}) / (0.231\text{V}) = 14.4$  kV/cm / V.

### 2.4 Evaluation of the Temperature Sensor

The temperature sensor was not specifically tested. All measurements were conducted at room temperature, which appeared to have been measured correctly by the temperature sensor. The Mars vacuum chamber, which will be able to simulate the range of temperatures and atmosphere, was under construction while this research was being conducted, but can it can now be used to test the entire MECA Electrometer under simulated Martian surface conditions.

## 3. Conclusions

Although the rubbing experiment using Martian soil simulant (JSC Mars-1) could not be performed in a low CO<sub>2</sub> atmosphere, the rocking experiment described in Section 2.1.2 could be conducted in either the glove box in dry air, or in the small vacuum chamber in a low CO<sub>2</sub> atmosphere. We found that there was not a significant amount of difference observed in the tribo sensor output using the rocking chamber in a low CO<sub>2</sub> atmosphere or in dry air at atmospheric pressure. This would suggest that if the rubbing

experiment had been performed in a low CO<sub>2</sub> atmosphere, then the tribo sensor responses would not be much different than in the dry air environment. The observation that the tribo sensors developed such little electric charge would indicate that the MECA Electrometer's triboelectric sensor circuitry should be modified to provide a larger gain (increased sensitivity) that would allow the charge buildup to be more accurately measured. From Figure 3, we see that when the maximum tribo output voltage change is measured to be 0.04 V for Rulon J<sup>TM</sup>, it appears that as little as (40 mV/ 4096 mV x100%) = 1% of the A/D converter's range is being utilized. If a utilization of 50% of the full range is desired, then the overall tribo circuit's gain should be increased by a factor of 50. Finally, the largest output voltage that could be obtained by vigorously rubbing the tribo materials with wool was 1.5 V, which corresponds to only 18% of the full range of the A/D converter.

The performance of the ion gauge was found to be near ideal. The current sensitivity was calculated to be 42.2 pA/V. That is, if the ion gauge output voltage was measured to be 0.002 V (2mV) corresponding to the bit resolution of the A/D converter, then the ion current would be 84.4 fA, which is very close to the input bias current of the LMC 6044 op amp used in the current-to-voltage converter.

The sensitivity of the local electric field sensor was measured to be 14.4 kV/cm / V. That is, at a plate separation distance of 0.3 cm and with a 1 kV potential difference between parallel plates, the electric field sensor produced an output voltage of 0.231 V.

The temperature sensor consisted of a dedicated integrated circuit chip. Since all experiments that were conducted during this research were at room temperature, the temperature sensor's performance under simulated Martian temperature conditions was not determined.

## **Acknowledgements**

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## **References:**

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